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Increasing Casting Speed in High Carbon and Micro Alloy DIN EN ISO 16120-2: 2011-C66D Steels

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Abstract: Different parameters can be used together in the continuous casting process known as an important steel production stage in the world. It is important to use metallurgical appropriate parameters to meet the product properties. Many innovations have been made in the continuous casting process from past to present. It is known that studies are carried out on many effective topics such as steel analysis, refractory materials, continuous casting parameters, in order to make the proper solidification that will meet the needs with its continuous casting capabilities. When continuous casting parameters are examined; the casting speed parameter was found to be effective in terms of quality needs in macro samples. Therefore, in this study, the effect of the increase of casting speed parameters on the quality of macro samples was investigated. As a method; in high carbon, micro-alloyed DIN EN ISO 16120-2: 2011-C66D quality steels, in different castings, this parameter was changed and macro samples were taken and evaluated in terms of quality needs. When macro sample quality results are compared; the effect of casting speed was observed. In this study; the effect of the increase in casting speed in continuous billet casting facility on optimum metallographic and physical quality has been investigated and the results have been interpreted.

Keywords: Iron steel, steel production, continuous casting, casting speed

Yüksek Karbonlu ve Mikro Alaşımlı DIN EN ISO 16120-2:2011-C66D Çeliklerde Döküm Hızının Artırılması

Öz: Dünyada önemli bir çelik üretim aşaması olarak bilinen sürekli döküm prosesinde, farklı parametreler bir arada kullanılabilmektedir. Ürün özelliklerinin karşılanmasında metalurjik açıdan uygun parametrelerin kullanılması önem arz etmektedir. Sürekli döküm prosesinde geçmişten günümüze birçok yenilik gerçekleştirilmiştir. Sürekli döküm kabiliyetleri ile ihtiyaçlara cevap verecek uygun katılaştırmanın optimum düzeyde yapılabilmesi amacıyla çelik analizleri, refrakter malzemeler, sürekli döküm parametreleri gibi etkili bir çok konu üzerinde çalışmaların yapıldığı bilinmektedir. Sürekli döküm parametreleri incelendiğinde; döküm hızı parametresinin makro numunelerdeki kalite ihtiyaçları açısından etkili olabileceği görülmüştür. Bu nedenle, bu çalışmada döküm hızı parametresi artışının makro numunelerdeki kaliteye etkisi araştırılmıştır. Yöntem olarak; yüksek karbonlu, mikro alaşımlı DIN EN ISO 16120-2:2011-C66D kalite çeliklerde, farklı dökümlerde söz konusu parametre değiştirilerek makro numuneleri alınmış ve kalite ihtiyaçları açısından değerlendirilmesi yapılmıştır. Makro numune kalite sonuçları karşılaştırıldığında; döküm hızının etkisinin gözlendiği görülmüştür. Bu çalışmada; sürekli kütük döküm tesisinde döküm hızı artışının, optimum metalografik ve fiziksel kaliteyi sağlayarak üretim artışına etkisi araştırılmış ve sonuçlar yorumlanmıştır.

Anahtar kelimeler: Demir çelik, çelik üretim, sürekli döküm, döküm hızı.

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1. Introduction

Developing world conditions and changing competition conditions lead companies to search for new technology. One of the best conditions for competition is to produce products with high profit margins and thus to make production profitable. The biggest supporter of profitability in production is undoubtedly to increase production efficiency to the highest levels. The iron and steel industry is a constantly developing sector. As of 2019, the world's total steel production amounted to 1.869 billion tons. Steel production increased by 3.4% in 2019 [1]. In continuous billet casting production in iron and steel facilities, some studies were conducted in previous periods, considering the optimization of process parameters and quality requirements. [2,3,4]. However, improvement study of billet casting speed of high carbon and micro-alloyed DIN EN ISO 16120-2: 2011-C66D quality steel, which is also referred to as carbon steels suitable for micro-alloyed high strength wire-spring-rope manufacturing, was not encountered in previous periods. Continuous billet casting process studies in other subjects within the scope of this study are given below.

In the study by C. Li, B.G. Thomas [5], titled as “Maximum casting speed for continuous cast steel billets based on sub-mold bulging computation”, a computational study has been performed in 120, 175 and 220 mm square sizes in order to determine the maximum casting speed based on sub-mold swelling and corner crack defects [6, 7]. S. Semplici, R. Karan, C. Mapelli [8] conducted a study on mold corner design for high speed casting, which is titled as “Diamold design of corners in billet high speed continuous casting” [9, 10]. In the study by Xiao, C., et al. [11] , which is titled as “Control of macrosegregation behavior by applying final electromagnetic stirring for continuously cast high carbon steel billet”, it has been stated that the solidification and segregation will be the optimum value with the final electromagnetic mixer (F-EMS) at a casting speed of 1.65 meters/minute in 0.77% carbon SWRH77B quality steel with 360-ampere current/12 hertz frequency [12, 13, 14].

In the study of Su, et al. [15], which is titled as “Heat transfer and central segregation of continuously cast high carbon steel billet”, it has been studied that the optimization of the secondary cooling with the billet surface temperature value and the casting of the center segregation with F-EMS at a speed of 1.7 meters/minute may be appropriate in 160x10 mm size 0.81% carbon SWRH82B quality steel [16, 17]. In the study by Luo, et al. [18], which is titled as “Numerical Simulation and Experimental Study of F-EMS for Continuously Cast Billet of High Carbon Steel”, it has been studied with Ansys and CFX software that center segregation can be at optimum with 380-ampere current/6 hertz frequency value of F-EMS value at a casting speed of 1.9 meters/minute in 160x160 size [19, 20]. In the study by Mortan, et al. [21], which is titled as “Next Steps in High-Speed Billet Casting at Ege Celik (Aliaga, Turkey)”, the speed increase of 6.2 meters/minute in 130x130 mm cross-section in steels up to 0.19% carbon with equipment changes was examined. In the study by scientists Cobelli, et al. [22], which is titled as “Fast Casting of 150 sq billets-boost of productivity”, the sub-mold additional role, the design changes made in the mold water grooves of the chrome-plated mold and the design changes in the in-mold transition grooves as well as the high casting speed of 5.6 meters/minute were examined in the production of 150x150 size in 0.32% carbon steel [23].

As can be seen from previous studies, higher casting speeds in different grades, optimization of equipment parameters and quality requirements have been studied in billet casting production [24, 25]. However, improvement study of billet casting speed of high carbon and micro-alloyed DIN EN ISO 16120-2: 2011-C66D quality steel, which is also referred to as carbon steels suitable for micro-alloyed high strength wire-spring-rope manufacturing, was not encountered in previous periods. In this study, the speed increase in the continuous billet casting process has been tried to be achieved without deteriorate the meallographic internal structure, physical properties and quality of the steel billet produced and by keeping the product defects specified in the standards to a minimum. It is aimed to increase the production resulting from the increase in speed by considering the quality requirements.

2. Material and Method

2.1. Raw Materials Used in the Study

In continuous casting processes, it is generally produced in two ways, horizontal and vertical. The horizontal casting style has many superior aspects compared to vertical casting styles. Therefore, horizontal casting type is preferred within the bounds of possibility. It is possible to cast all non-ferrous metals horizontally [26, 27]. Types of continuous casting plant can be grouped under the headings of a vertical, vertical twisted, circular arc and oval curved continuous casting machines. Continuous casting methods are shown in Figure 1.

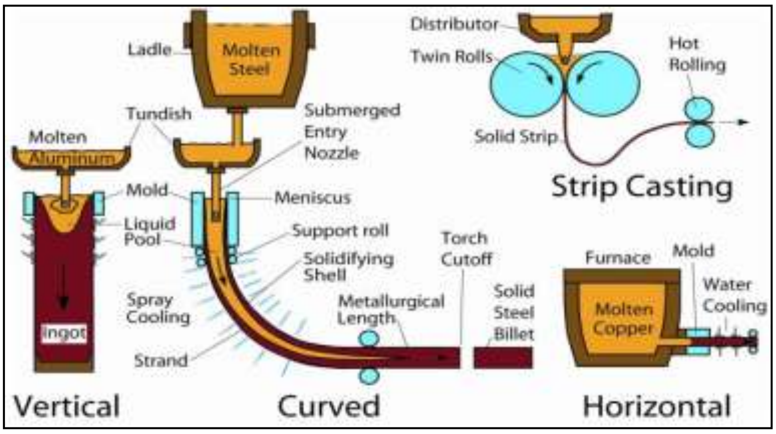

Figure 1. Continuous casting methods [29].

The main raw material used in the study is high carbon and micro-alloyed DIN EN ISO 16120-2: 2011-C66D quality steel. The study was performed by a closed casting process, the material used is the final product of the continuous billet casting machine of an integrated (where coke, sinter, blast furnace, steelwork, continuous casting, rolling mill facilities coexist) iron steel facility. The steel billet used in the tests is the highest tonnage steel quality produced by the closed casting process at the aforementioned facility. High carbon and micro-alloyed DIN EN ISO 16120-2: 2011-C66D quality steel, which has added value under competitive conditions, is used in the production of high strength wire-spring-rope.

Table 1. Chemical analysis table of the standard used for billet steel (DIN EN ISO 16120-2: 2011-C66D)

C%	Mn%	P%	S%	Si%	Al%	Ti%	Nb%	V%	B%
0.65	0.60	0.012	0.012	0.20	0.010	0.010	0.008	0.010	0.0045
Ni%	**Cu%**	**Cr%**	**N ppm**	**Mo%**	**Sn%**	**Pb%**	**Mn/S**	**C%**	**Ca**
0.08	0.10	0.080	90	0.015	0.015	0.010	35	-	-

Macro samples of 130x130x30 mm were taken with an oxy gas cutting system. Macro samples marked with the casting number and channel information have been prepared to make them suitable for examination in a laboratory environment.

The test samples were milled on the milling machine to smooth their surfaces. In each casting produced, one macro sample was taken from each channel in the last 60-80 tons of the melting pot for testing. Cutting the samples at a suitable size is presented in Figure 2-a and the numbering of the cut materials is presented in Figure 2-b. In the experiment, a total of 18 samples were selected in the three aforementioned castings and 10 of them were found suitable for examination.

Figure 2. a) Macro sample cutting process b) Casting channel numbering

Figure 3. Milling processing machine

The milling processing machine we used in this study is presented in Figure 3. Samples, whose surface treatment has been completed by milling, are placed in the macro sample manipulation basket for etching.

Figure 4. a) Acid tank b) Rinsing tank c) Surface cleaning

A suitable mixture was prepared with 40% HCl (38%) and 60% water for etching of the samples placed in the macro sample manipulation basket. The prepared mixture samples were kept in acid tanks that are large enough for etching, and they were etched for 50 minutes. Most of the metallurgical examination is made after etching the polished surfaces with a suitable chemical solution. The surface of the macro sample to be checked may be contaminated by external structures such as grease or oil, and there may also be stains and discoloration due to rust. The surface to be checked underwent etching bath and the existing acid, rust or oxide layer was removed without damaging the metal. After the etching process was completed, the samples were rinsed in an alkaline solution for 15-30 seconds. Acid rinsing and changing apparatus of macro sample manipulation basket was used for manipulation in etching and rinsing processes. After rinsing, surfaces were cleaned with water and alcohol.

Figure 5-a) Macro samples to be examined, b) Macro examination and photographing of samples

The macro samples to be examined is presented in Figure 5-a. As seen in Figure 5-b, macro sample examination and photographing have been done in a machinery with appropriate lighting. SEM-EDS and optical microscope images were taken and examined after sanding and polishing to examine the micro structures of billet steel samples. Jeol JMS-6510 SEM and Nikon Epiphot 200 optical microscope were used in the image examinations on the samples. In addition, XRD and Autoquan analysis studies were performed on samples. Preliminary evaluation of defects and other parameters in macro samples was performed by taking into consideration ASTM E381 (Standard method of macro etch testing steel bars, billets, blooms, and forgings1) standard [28] and also the Billet Internal Structure Defects section of the "Long Product Defect Catalog" prepared by the iron and steel factories where the experimental study was conducted.

2.2 Method

This study aims to increase the continuous casting production rate by optimizing the operating parameters and to investigate the effect of the steel material produced on the quality parameters. This study also aims to optimize the process parameters without decreasing the quality in the production with 3.2 meters/minute casting speed of high carbon and micro-alloyed DIN EN ISO 16120-2: 2011-C66D quality steel produced at 2.8 meters/minute casting speed under current operating conditions. The steel produced in this article has been investigated whether its mechanical and physical structure is within the framework of quality standards in terms of macro and micro examinations.

3. Research Results and Discussion

3.1 Experiment Data

The temperature of the liquid steel in the tundish (target value between 1510 and 1520 ^{o}C) was measured. The casting speed, electromagnetic stirring in mold (M-EMS) and specific water volume values were changed, and 10 different test studies were performed in three different castings with approximately 600 tons of liquid steel. Experimental groups and test studies are presented in Table 2. The first group is experimental study 1, 2 and 3, and the second group is experimental study 4,5,6,7,8 and the third group study is 9 and 10.

In the first group test study, it was taken as a basis that the speed could be increased and the optimization of the M-EMS value. In the first group experimental study, the casting speed of 2.8 meters/minute was increased to 2.9 meters/minute and 3.0 meters/minute. The optimization of the M-EMS value was performed at a casting speed of 2.8 meters/minute. In the second group experimental study, it was taken as a basis that the speed can be increased to 3.2 meters/minute after the optimization of the M-EMS value and that the speed can also be increased in a different casting.

Depending on the suitability of the second group experimental study quality results, a third group experimental study was performed in another casting. In the third group experimental study, it was taken as a basis that solidified shell sufficiency is provided to prevent shell ruptures that may occur due to ferrostatic pressure in the liquid steel with the increase of the specific secondary cooling water volume after optimizing the M-EMS value and increasing the speed to 3.2 meters/minute and that speed can also be increased for a different casting.

Table 2. Parameters applied in experiments

Test Group	Test No	M-EMS (current/frequency)		Secondary Cooling (liter/kilogram)		Casting Speed (meter/minute)	
		Routine Application	Test Application	Routine Application	Test Application	Routine Application	Test Application
1	1	360/5	400/5	0.95	0.95	2.8	2.8
	2	360/5	400/5	0.95	0.95	2.8	2.9
	3	360/5	400/5	0.95	0.95	2.8	3.0
2	4	360/5	400/5	0.95	0.95	2.8	2.8
	5	360/5	400/5	0.95	0.95	2.8	2.9
	6	360/5	400/5	0.95	0.95	2.8	3.0
	7	360/5	400/5	0.95	0.95	2.8	3.1
	8	360/5	400/5	0.95	0.95	2.8	3.2
3	9	360/5	400/5	0.95	0.95	2.8	3.2
	10	360/5	400/5	0.95	1.27	2.8	3.2

While evaluating the experiments, the data of different operational parameters were used by considering the quality requirements. The experimental study in three different castings was evaluated in three groups. The parameters applied in the first experiment group 1, 2 and 3 test study shown in Table 2. In summary, in the first group first casting experiment, the speed can be increased and the optimization of M-EMS value has been taken as a basis.

Depending on the suitability of the first group experimental study quality results, second group experimental study was conducted in another casting. The parameters applied to the tests 4, 5, 6, 7 and 8 in the second group of steel billets in a different casting are shown in Table 2.

In summary, in the second group, second casting experimental study, it was taken as a basis that the speed could be increased to 3.2 meters/minute after optimization of the M-EMS value and also the speed could be increased in a different casting. Depending on the suitability of the second group experimental study quality results, a third group experimental study was performed in another casting. Application parameters given in Table 2, the third experimental groups 9 and 10 which effect the process of the test work are summarized below.

In summary, in the third group experimental study, it was taken as a basis that solidified shell sufficiency is provided to prevent shell ruptures that may occur due to ferrostatic pressure in the liquid steel with the specific increase of the secondary cooling water volume after optimizing the M-EMS value and increasing the speed to 3.2 meters/minute and that speed can also be increased for a different casting.

In the tests applied with the application of 0.95 liter/kilogram specific water volume, the secondary cooling zone applied from experiment 1 to experiment 9, it showed a distribution of 0.26 liter/minute in zone 1, 0.30 liter/minute in zone 2a, 0.16 liter/minute in zone 2b, 0.11 liter/minute in zone 3a, 0.12 liter/minute in zone 3b throughout the line. In the test study performed by increasing the secondary cooling zone-specific water volume to 1.27 liter/kilogram in Experiment 10, it showed a distribution of 0.36 liter/minute in zone 1, 0.38 liter/minute in zone 2a, 0.20 liter/minute in zone 2b, 0.11 liter/minute in zone 3a, 0.12 liter/minute in zone 3b, 0.11 liter/minute in zone 3c throughout the line. The distribution of the specific water volume applied in the tests in the continuous casting secondary cooling zone by region is shown together in Figure 6.

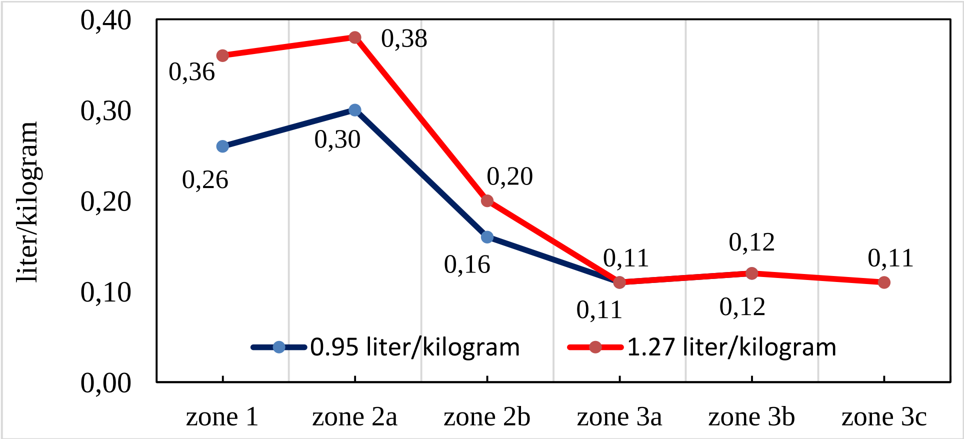

Figure 6. Specific water volume variation in secondary cooling zones of billet samples

It is aimed to ensure the sufficiency of solidified hardening shell to prevent shear ruptures that may occur due to ferrostatic pressure in the liquid steel with the increase in specific secondary cooling water volume. While cutting the billet material, it is desired that solidification is completed and there is no liquid steel in the billet. Otherwise, it may cause very serious occupational health and safety risks in addition to serious production losses. Therefore, attention has been paid to determining the secondary cooling process parameters to ensure proper solidification.

3.2. Macro Examination at Different Casting Speeds

3.2.1 First Group Experimental Tests

Test studies conducted in the first group include the experiments 1, 2 and 3 shown in Table 2. In the test studies, the M-EMS 360 amp current/5 hertz frequency value that was routinely studied without changing the existing operating parameters was changed to 400 amp current/5 hertz frequency for each trial (Table 2). In the first type experiment, the casting speed was not changed and it was performed at 2.8 meters/minute, which is traditionally applied by the enterprise (macro sample image Figure 7-a). In the 2nd and 3rd test studies, the tests were carried out by increasing the operating routine 360 current/5 hertz value to 400 ampere current/5 hertz frequency for each test without making changes in the existing operating parameters. The casting speed was increased from the speed of 2.8 meters/minute for each test to 2.9 and 3.0 meters/minute, respectively (macro sample images Figure 7-b and c).

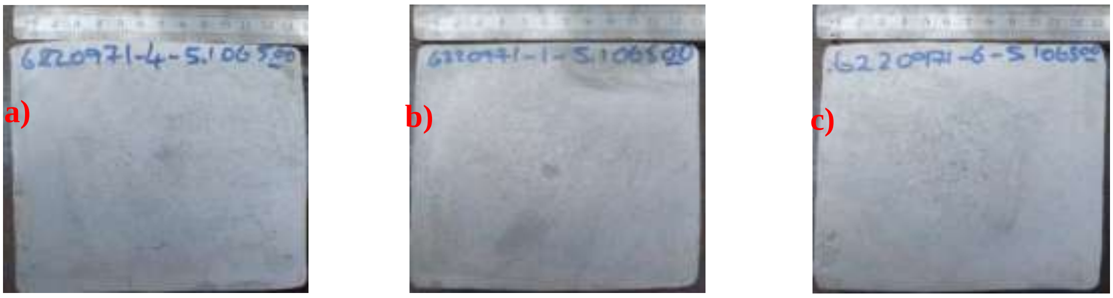

Figure 7. Steel billet macro sample 1st group experimental test pictures a) No: 1, Casting speed: 2.8 m/min.; b) No: 2, Casting speed: 2.9 m/min.; c) No: 3, Casting speed: 3.0 m/min.

Continuous casting quality standards were ensured in group 1 experimental tests. As can be seen in Figure 7-a, b, c), center segregation, center withdrawal cavity, center star crack, gas gap, inclusion band, halfway crack, diagonal crack defects were at an acceptable level based on the defects in the long product defect catalogue in group 1 macro sample test studies. The segregation structure observed outside the central structure is related to steel cleaning and is at an acceptable level. Since the diagonal differences of the shape of the billet and the non-uniform structure near the edge meet the dimensional needs, no inconvenience has been observed. After confirming that the first group experimental test results were within the acceptance criteria, the second group experimental studies were started.

3.2.2 Second Group Experimental Tests

The studies in the second group include the tests carried out in the second casting, which covers the tests numbered 4,5,6,7,8 shown in Table 2. In the 4th experiment, the M-EMS 360-ampere current/5 hertz frequency value, which was routinely produced without changing the existing operating parameters, was increased to 400-ampere current/5 hertz. The test was performed on a different casting without changing the traditionally applied 2.8 meters/minute casting speed. As seen in Table 2, the operating routine of M-EMS 360-ampere current/5 hertz frequency value was increased to 400 ampere current/5 hertz frequency for each experiment in the experiments 5, 6, 7 and 8, respectively. In addition, the tests were performed by increasing the casting speed of 2.8 meters/minute, which is traditionally applied in continuous casting, to 2.9 meters/minute, 3.0 meters/minute, 3.1 meters/minute and 3.2 meters/minute for each test, respectively. Macro images of steel billets produced at each production speed in the second group are presented in Figure 8-a, b, c, d, e respectively.

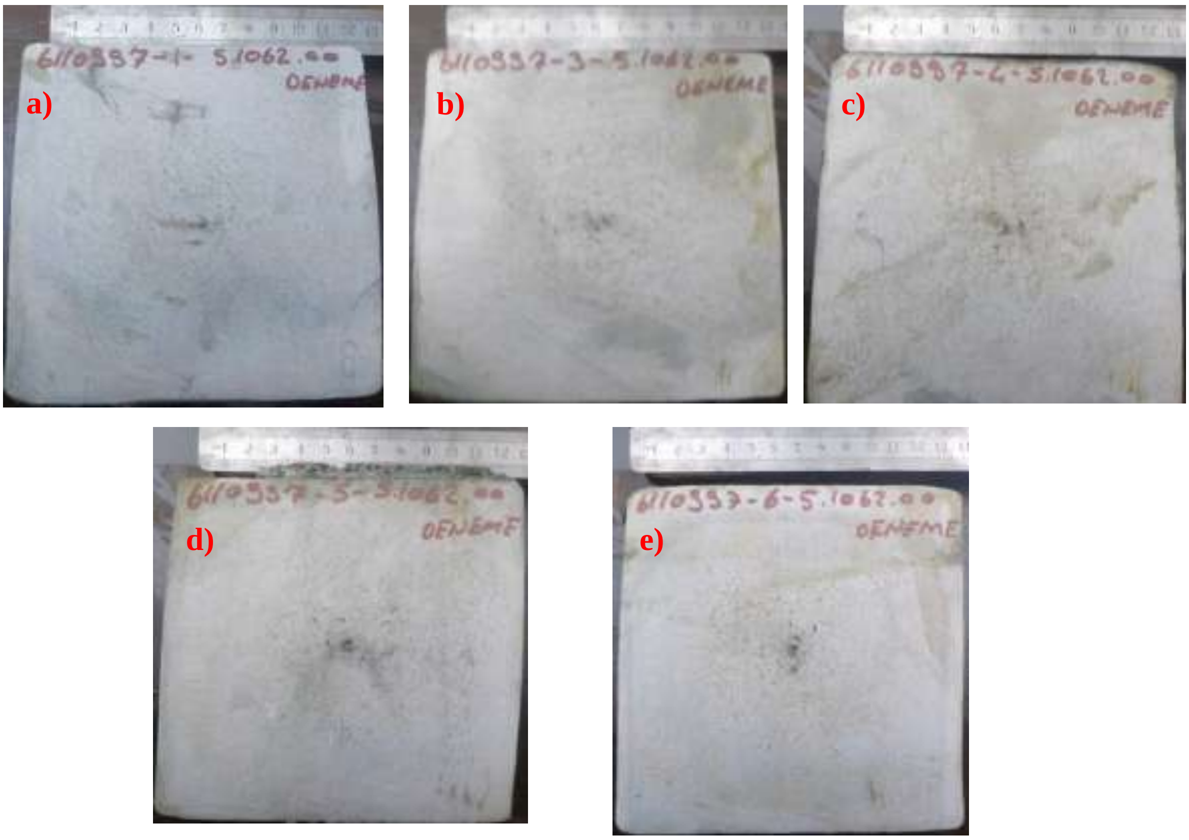

Figure 8. Macro sample pictures of second group experimental tests of a steel billet samples a) No: 4, Casting speed: 2.8 m/min., b) No: 5, Casting speed: 2.9 m/min., c) No: 6, Casting speed: 3.0 m/min., d) No: 7 , Casting speed: 3.1 m/min. e) No: 8, Casting speed: 3.2 m/min.

During the 2nd group test studies, the desired quality for continuous casting has been reached. As can be seen in the macro sample picture in Figure 8, it is seen that the defects in the manufactured products are within acceptable limits according to the long product defect catalogue. After the second group tests were completed, the third group tests were started.

3.2.3 Third Group Experimental Tests

The studies in the third group involve the studies including the 9th and 10th experiments shown in Table 2. In the third group tests, both tests were performed by increasing the M-EMS 360 amp current/5 hertz frequency value in the routine operation to 400 amp current/5 hertz frequency. Secondary cooling, 0.95 liter/kilogram specific water volume was kept constant in test no. 9 and the casting speed was increased from 2.8 meters/minute, which is the operating routine, to 3.2 meters/minute. In experiment 10, the secondary cooling specific water volume was increased from 0.95 liter/kilogram to 1.27 liter/kilogram and the casting speed was 3.2 meters/minute.

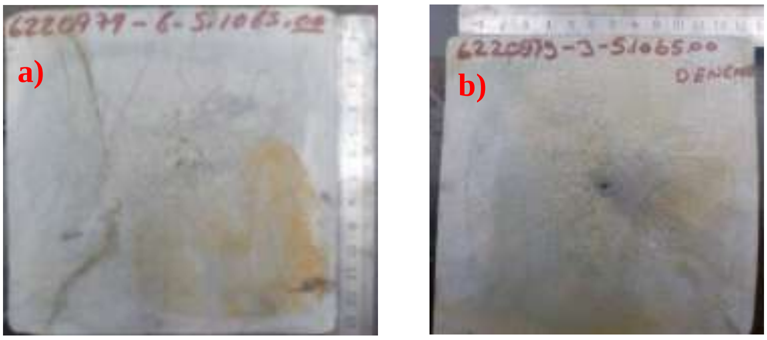

Figure 9. Macro sample pictures of third group experimental tests a) No: 9, volume of water 0.95 litre/kilogram, Casting speed: 3.2 m/min, b) No: 10, volume of water 1.27 litre/kilogram, Casting speed: 3.2 m/min.

In the continuous casting billet production experiments, no significant difference was observed between the casting speed of 2.8 meters/minute and the casting speed of 3.2 meters/minute that would negatively affect the billet quality in the phase structures formed within the steel body (Figure 9-a and b). Phase structures occurring during production may differ according to the working conditions and quality demands of the billet steel to be produced in the subsequent rolling production process.

3.3. Optical Microscope Examinations on the Billet Sample

In this study, samples for microscopic examinations and image analysis were prepared using Mecapress II specimen mounting press device and Phenolic Bakelite Powder. Metkon Digiset-2V device was used for grinding the sample. SiC foil emery was used with varying grit sizes namely respectively 180, 320, 600, 1200 and 2500 during the grinding process. After the grinding process, Struers Tegramin 25 polishing device was used to remove the sanding scratches on the surface and make the sample ready for optical examination. The polishing steps are 6µ, 3µ and 1µ and were carried out by using Polycrystalline Diamond suspension.

In the research, optical microscope examinations were made on the specimens produced in continuous castings using Nikon Epiphot 200 model microscope and X25, X100, X200, X500 magnifications.

In the study in the continuous casting facility, steel billets produced with a speed of 2.8 m/min, as seen in Figure 10, elongated grains were seen from the edge to the center at X25 magnification with an optical microscope. Ferrite structures that are formed at the grain boundary have been determined.

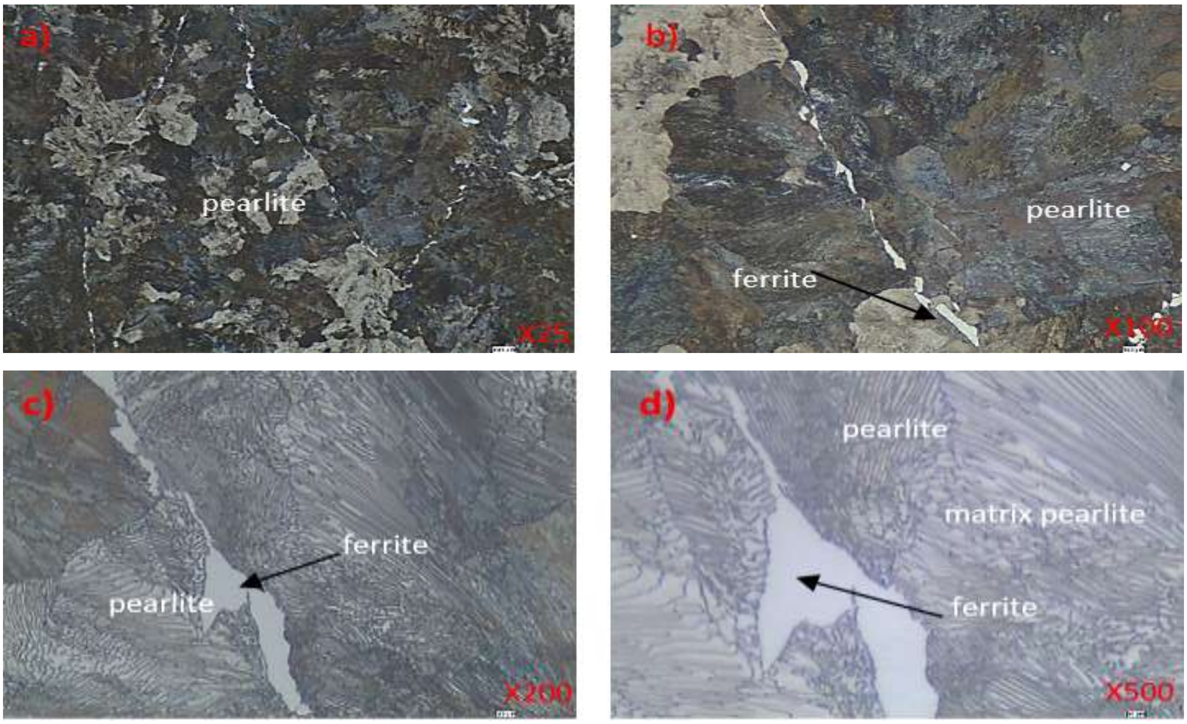

Figure 10. Optical microscope image of a steel billet sample produced with a casting speed of 2.8 m/min.

It has been seen that almost all of the building is perlite. In the layer defined as the mixed zone, there are impurities with lower oxidation potential [30]. Ferrite grains are rarely encountered throughout the building. It has been seen that the steel billet sample matrix is mostly composed of perlite structure. In Figure 10-b, perlite grains appeared at X100 magnification.

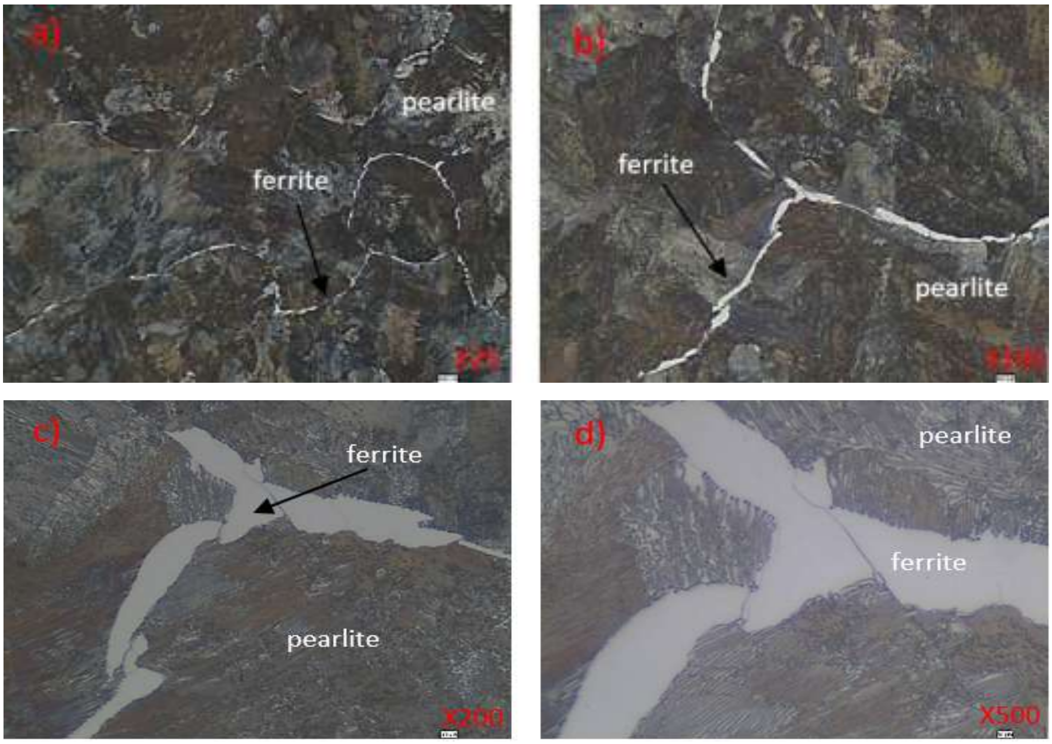

Figure 11. Optical microscope image of steel sample produced with a casting speed of 3.2 m/min.

In Figure 10-c, it has been seen that perlite grains are formed more clearly at X200 magnification. Lamellas in perlite grains began to appear. Perlite grains have been clearly seen at X500 magnification in Figure 10-d. It has been observed that the perlite grains and lamellae are larger in size.

As can be seen in Figure 11, it has been determined that the main structure of the steel billet matrix consists of perlite and there is a ferrite phase between the grain boundaries. As can be seen in Figure 11-a, longitudinally solidified grains has been detected at X25 magnification. Ferrite structures have been detected between the grain boundaries. It has been determined that the matrix texture of the steel billet sample consists of the pearlite phase. In the examinations performed with X100 magnification in Figure 11-b, it has been seen that pearlite phase grains emerged significantly. In the examination performed with X200 magnification in Figure 11-c, it has been seen that Perlite grains and ferrite structure look better. Lamellae within the perlite grains have started to appear more distinct. However, some ferrite can be lined along the high temperature rolling direction during production [31]. In Figure 11- d, perlite grains and lamellae intertwined with each other are clearly evident at X500 magnification.

3.4 SEM and EDS Examinations on Billet Sample

In the article study, SEM image and elution analysis were performed on slab samples produced in continuous castings on X250, X500, X1000, X2500 magnifications using Jeol JSM-6510 scanning electron microscope (SEM) with a resolution of 30 kV 3.0 nm. In element analysis, Oxford X MaxN50 detector with 124 eV resolution and EDS unit with inca and aztec software was used.

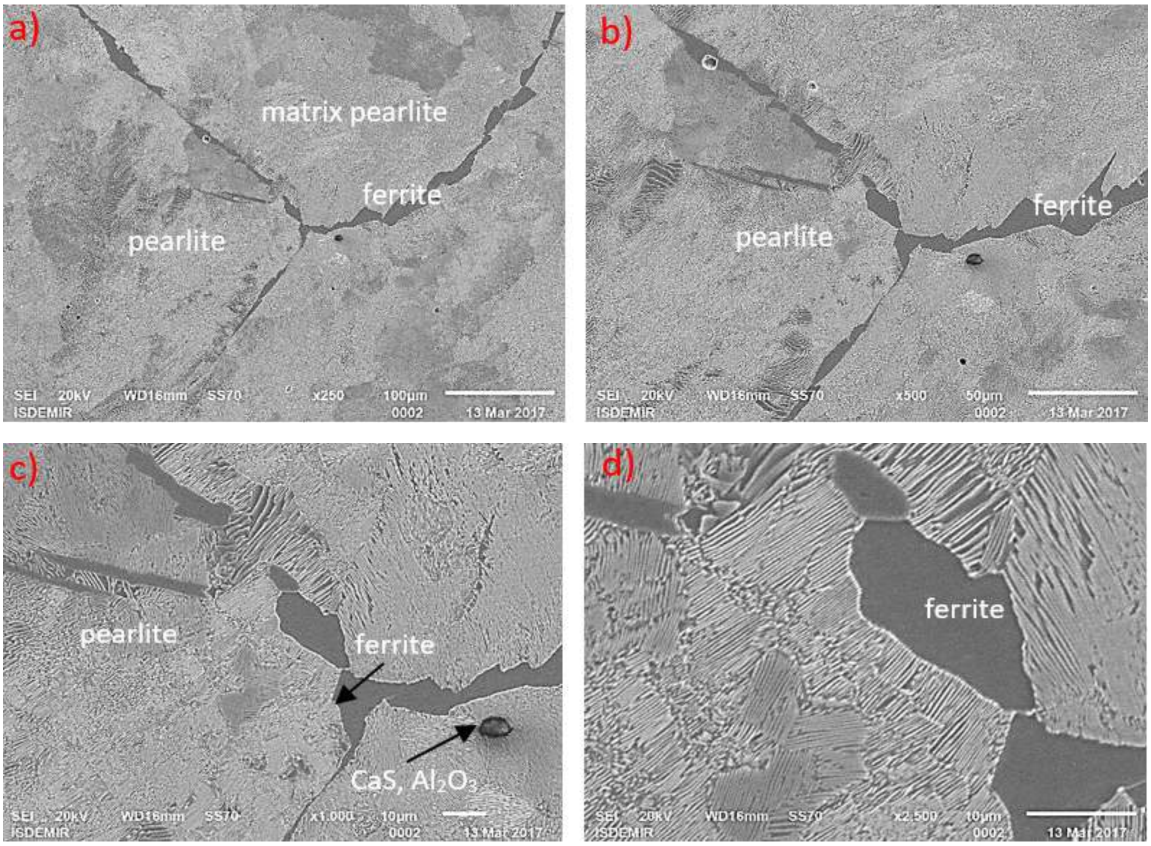

Figure 12. SEM image of billet steels produced with a casting speed of 2.8 m/min.

As seen in figure 12, structures similar to optical microscope images have been detected in SEM image on the samples taken in the production of a steel billet material with a speed of 2.8 m/min. In

Figure 12-a, it has been determined that almost all of the structure is perlite and there are ferrite structures at the grain boundary.

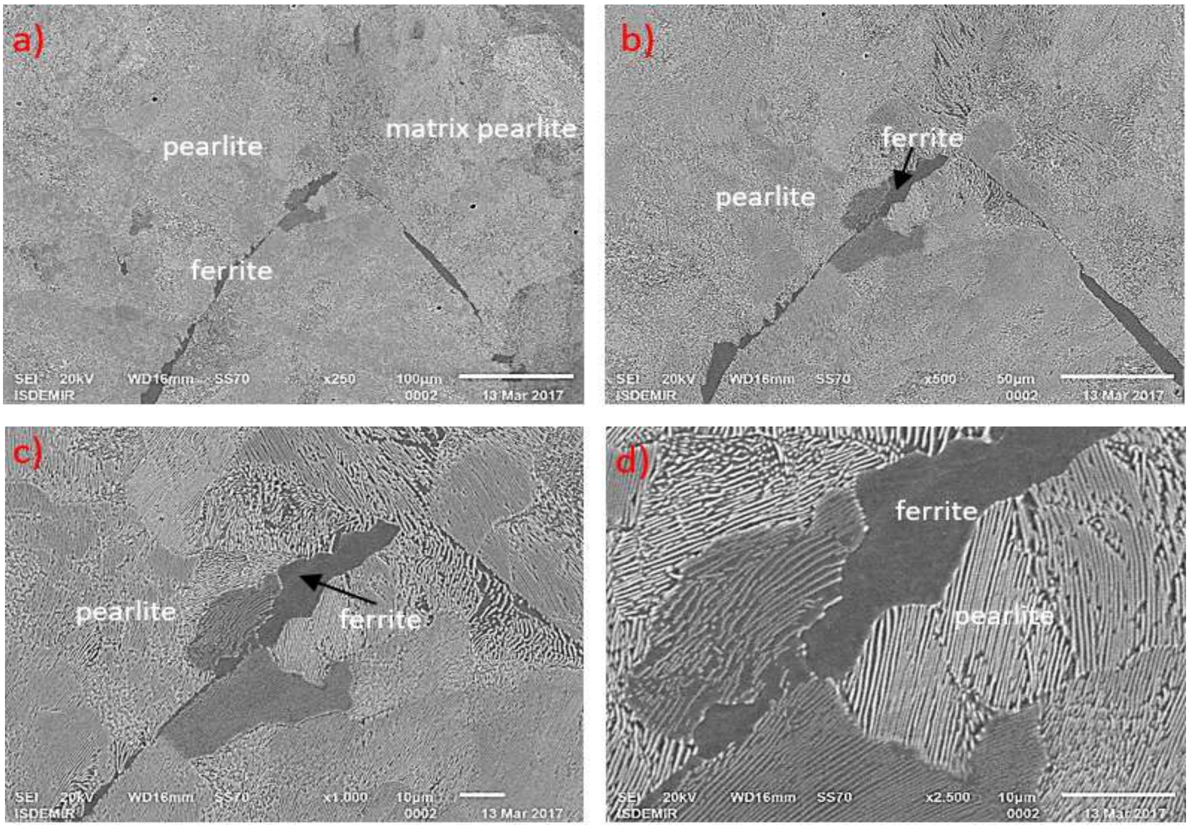

Figure 13. SEM image of billet steels produced with a casting speed of 3.2 m/min.

As seen in Figure 13, it has been determined that there were ferrite structures between the grain boundaries where the matrix consists of perlite, as expected in Figure 13, on the samples taken in the production of a steel billet material with a speed of 3.2 m/min. As the magnification rate increases, it can be seen in Figures 13-b, c and d that the perlite grains appear more clearly and the lamellas are more prominent. As examined in the optical microscope image, it was seen that most of the billet steel phase morphology was formed in the perlite structure.

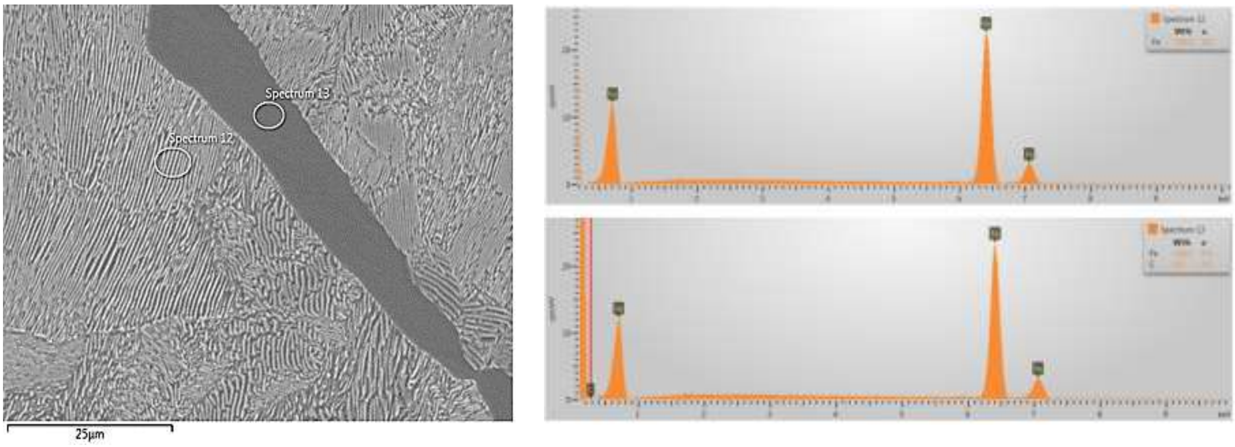

Figure 14. EDS image of billet steels produced with a casting speed of 2.8 m/min.

In EDS examinations on steel billet samples, Fe and C structures were determined in the analyses performed on steel billet samples produced at 2.8 m/min and 3.2 m/min casting speeds (indicated in Figure 14 and 15).

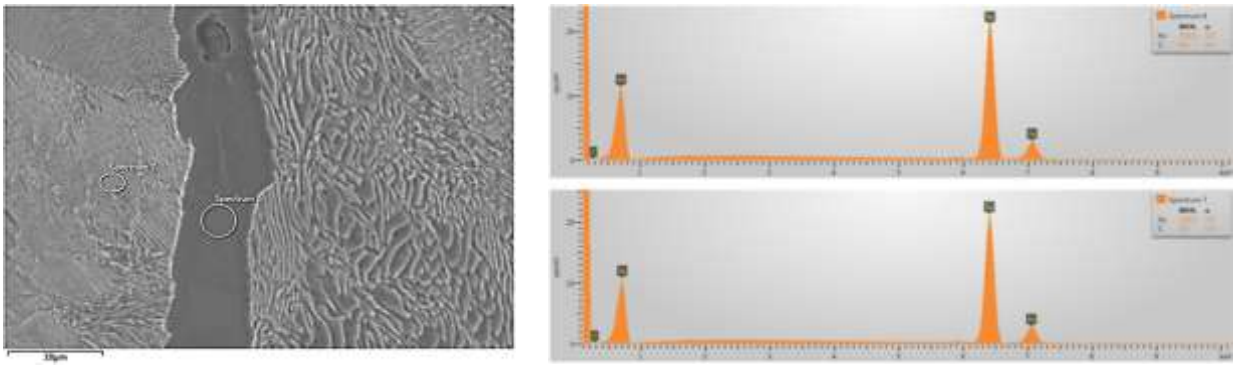

Figure 15. EDS image of billet steels produced with a casting speed of 3.2 m/min.

3.5 XRD and Autoquan Analysis Examinations on Billet Sample

In this study, the Rigaku XRD, Thermo-ARL XRF and Nikon optical microscope were used.

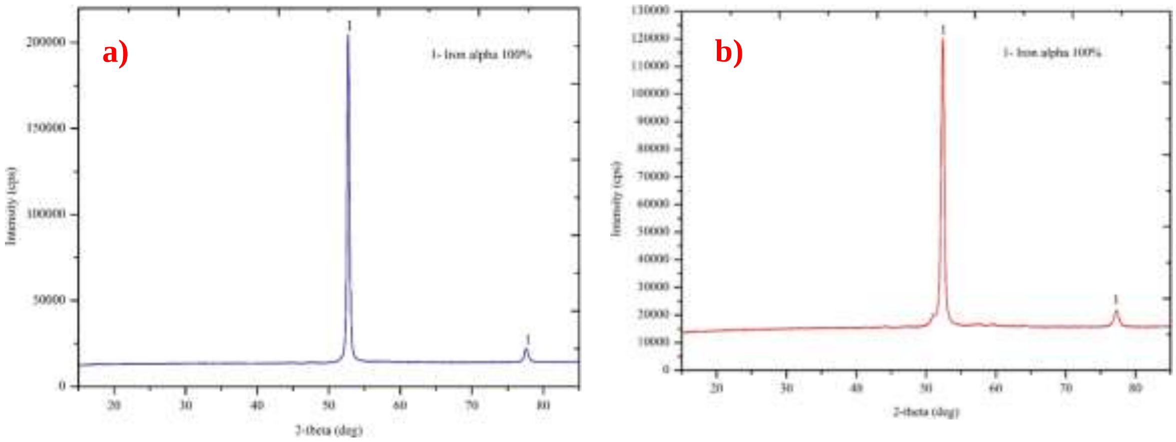

Figure 16. XRD analysis of a steel billet sample taken at a) 2.8 m/min and b) 3.2 m/min casting speeds

As can be seen in Figure 16-a), when we look at the phase structure with the XRD device; a high intensity (peak) value of 204.721 at 53^{o} at 2 theta (θ) angle was obtained in steels produced with a speed of 2.8 m/min. This situation can be explained by the slower cooling of the produced billet and the formation of crystal structures under more favourable conditions. As can be seen in Figure 16-b, when we look at the phase structure with the XRD; a lower intensity (peak) value was obtained as 119.989 at 53^{o} at 2 theta (θ) angle in steels produced with 3.2 m/min speed. This can be explained by the fact that the billet has cooled down faster and the crystal structures are not well-formed.

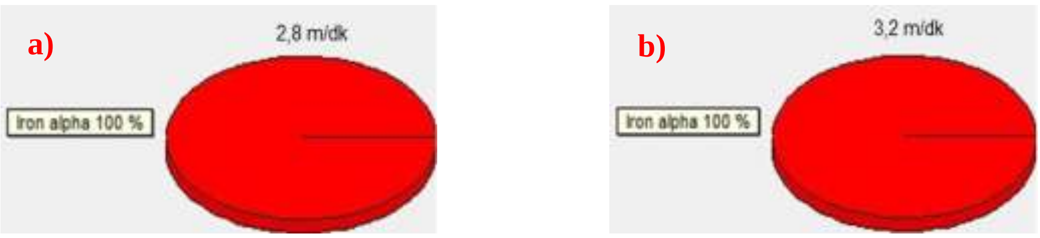

Figure 17. Autoquan program result for a) 2.8 m/min and b) 3.2 m/min casting speed of a steel billet sample

As can be seen in Figure 17-a and b), it was observed that the phase structure was 100% iron alpha phase structure at 2.8 m/min and 3.2 m/min casting speeds in the examination we made on the sample with the Autoquan program with the help of Rietveld method.

4. Conclusion and Recommendations

When the data obtained from the experiments performed for steel billet production at different speeds and the comparisons of these results are examined, it was seen that the speed of billet casting from 2.8 m / min to 3.2 m / min. Especially; it has been observed that an increase in production can be achieved by determining the casting speed, M-EMS and secondary cooling parameters by considering the quality expectations. It has been observed that it is possible to increase the speed of billet production with the prerequisite of meeting the quality needs in the case of liquid steel analysis and temperature values, equipment and operating parameters and operational operating conditions.

Considering the quality needs and production continuity, the production of 200 tons of liquid steel at a casting speed of 2.8 meters / minute in a continuous casting machine with 130x130 mm size and 6 channel casting is calculated as 133 tons / hour in theory. With the same process conditions, the casting speed of 3.2 meters / minute can be reached, resulting in a production amount of 152 tons / hour. The hourly production increase of 14% in continuous billet casting production provides a significant added value in market conditions and cost-oriented approaches.

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